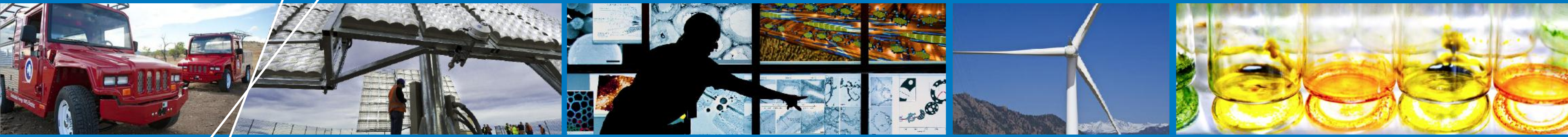
Amber LEDs for Solid-State Lighting:

White light with unprecedented efficiencies



Commercialization Webinar

December 10, 2013

Agenda for Today's Webinar

- Welcome/Logistics
- Technology Overview
- Commercialization Opportunity
- Q&A

Presenters

Kirstin Alberi, PhD
inventor

Yoriko Morita, PhD MBA
licensing manager

Technology Overview

- **Background/Context**
- **Limitations NREL's Technology Addresses**
  - Substrate material
  - Efficiency
  - Manufacturing
- **Performance Testing Results**
- **Summary of Benefits/Advantages**

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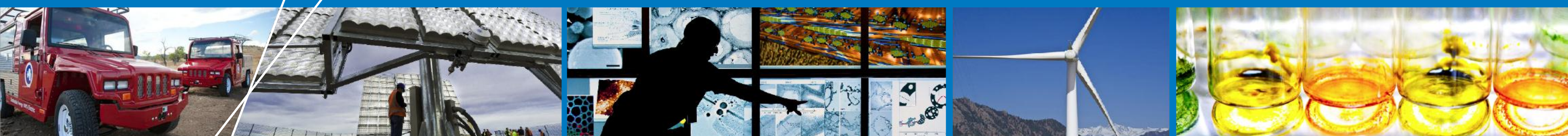
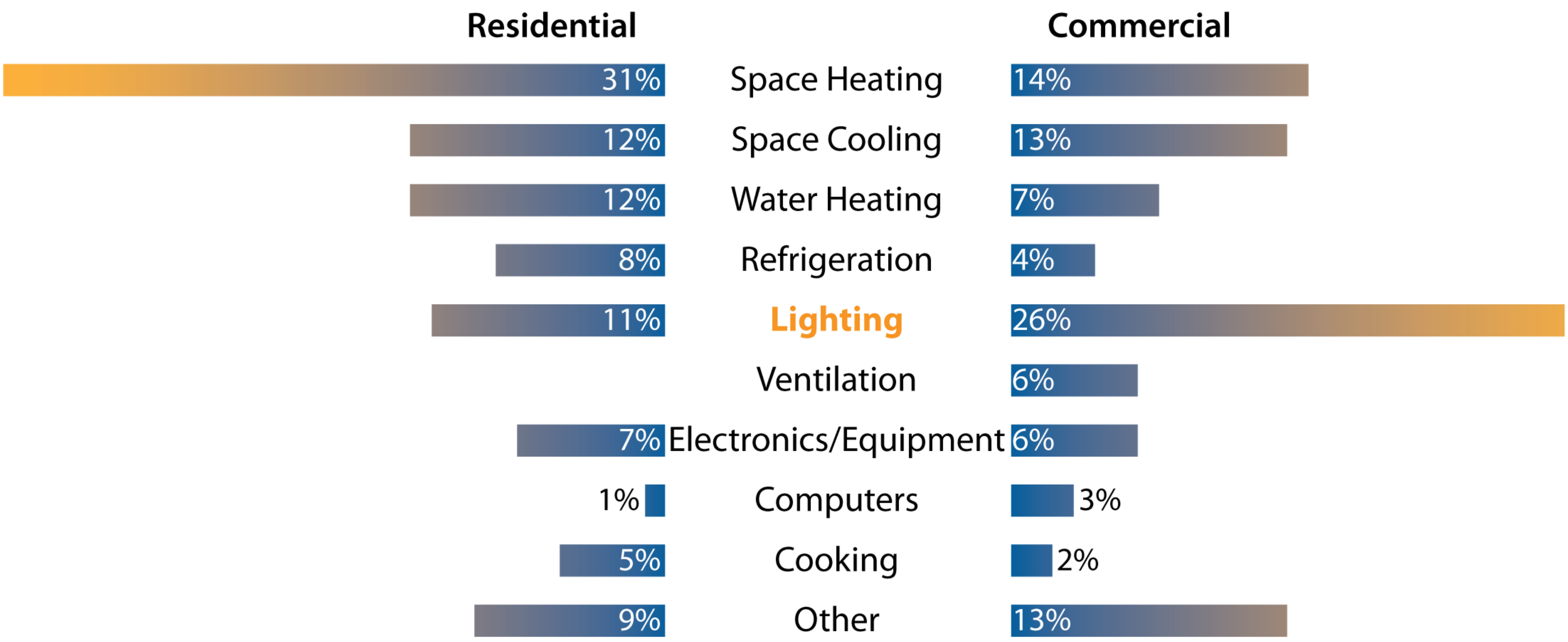


Background/Context

Breakdown of Energy Use in Buildings

- **Lighting accounts for a large share of energy use.**



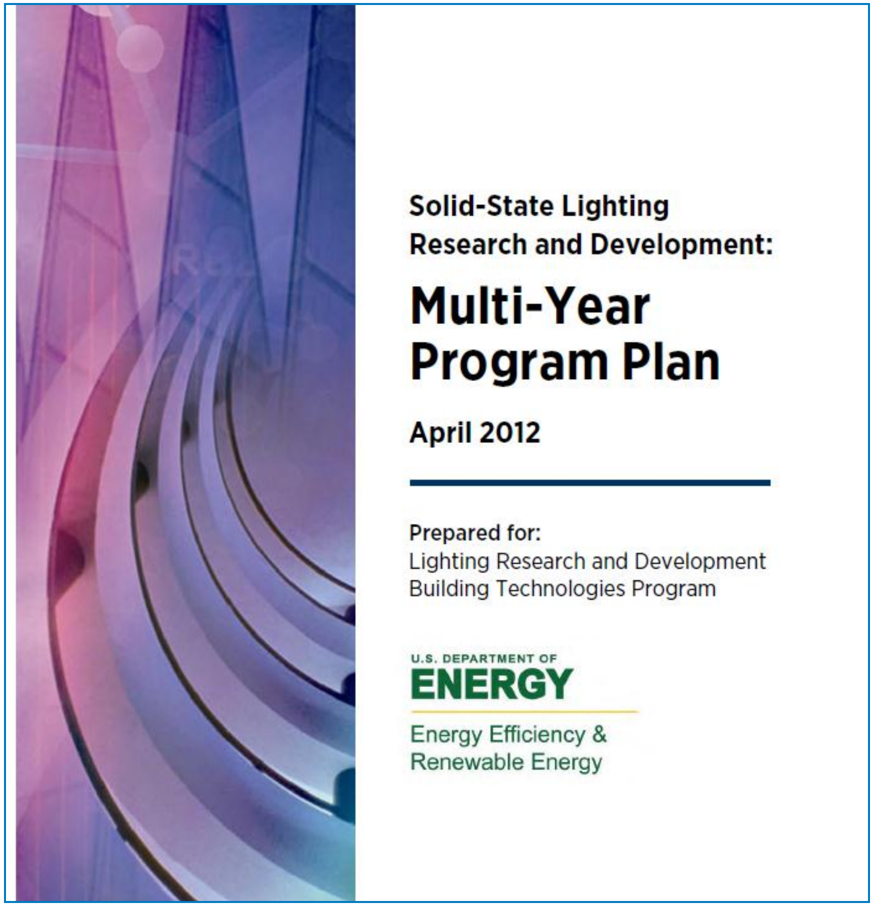
Source: *Energy Efficiency Trends in Residential and Commercial Buildings*, DOE Energy Efficiency and Renewable Energy Report, 2008

Breakdown of Energy Use in Buildings

- **Lighting accounts for a large share of energy use**
- **Solid-state lamps will reduce energy consumption**
  - 46% reduction in lighting energy consumption by 2030
  - 2,700 TWh cumulative energy savings 2010–2030
  - $250B cumulative cost savings 2010-2030

Source: *Energy Savings Potential of Solid-State Lighting in General Illumination Applications*, DOE Energy Efficiency and Renewable Energy Buildings Report, 2012

DOE’s Energy Efficiency & Renewable Energy (EERE) Mandate



“By 2025, develop advanced solid-state lighting technologies that… are much more energy efficient, longer lasting, and cost-competitive by targeting a product **system efficiency of 50 percent with lighting that closely reproduces the visible portions of the sunlight spectrum**.”

– *US Department of Energy*

The Goal

Enable white LED designs with improved efficiency and color control

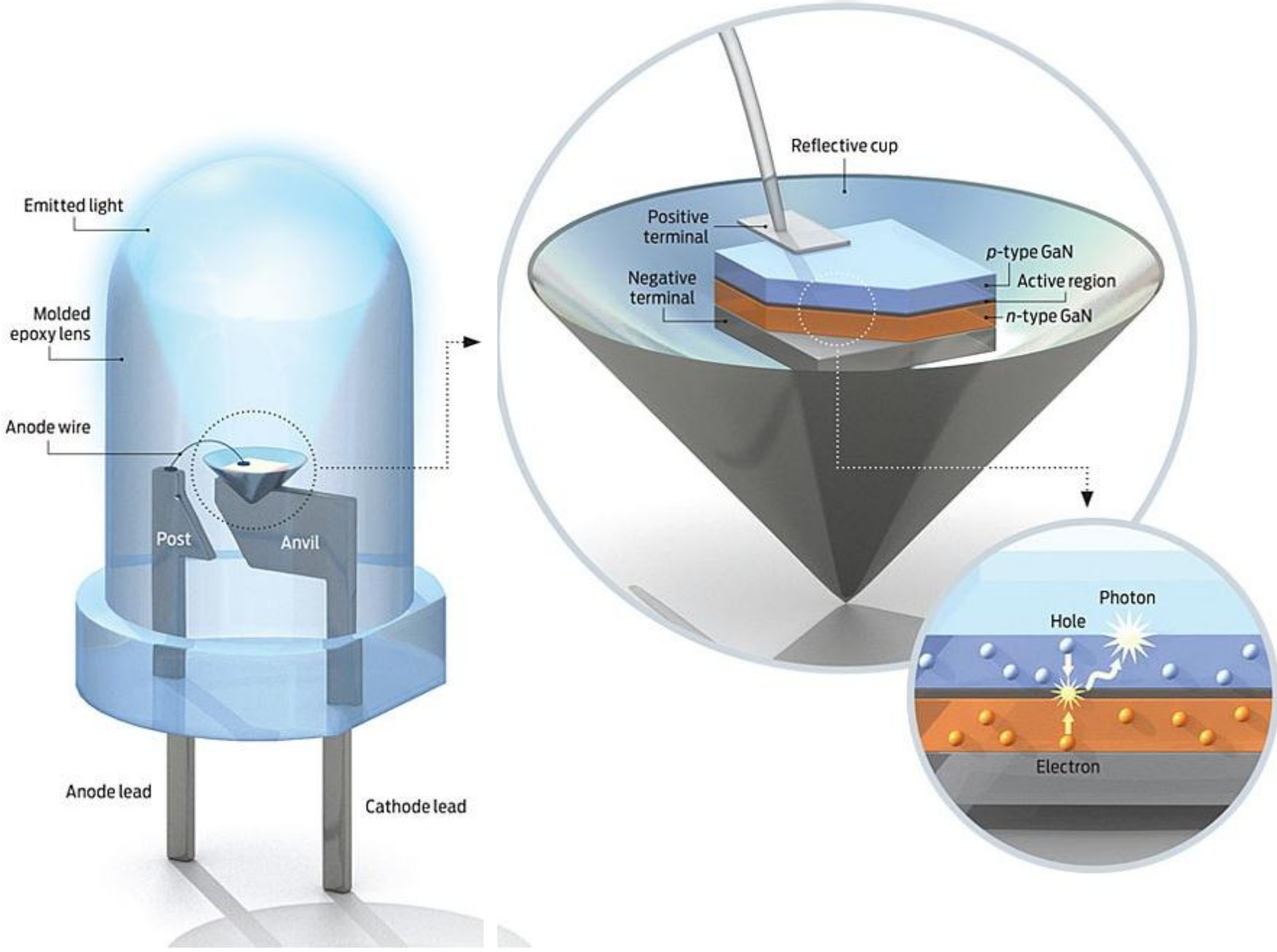
The Challenge:

New device designs are needed to improve the efficiency and color quality of white LEDs.

NREL's Solution:

New monochromatic LED technologies enabling multichip white LED designs with superior efficiency and color control to existing phosphor-converted architectures.

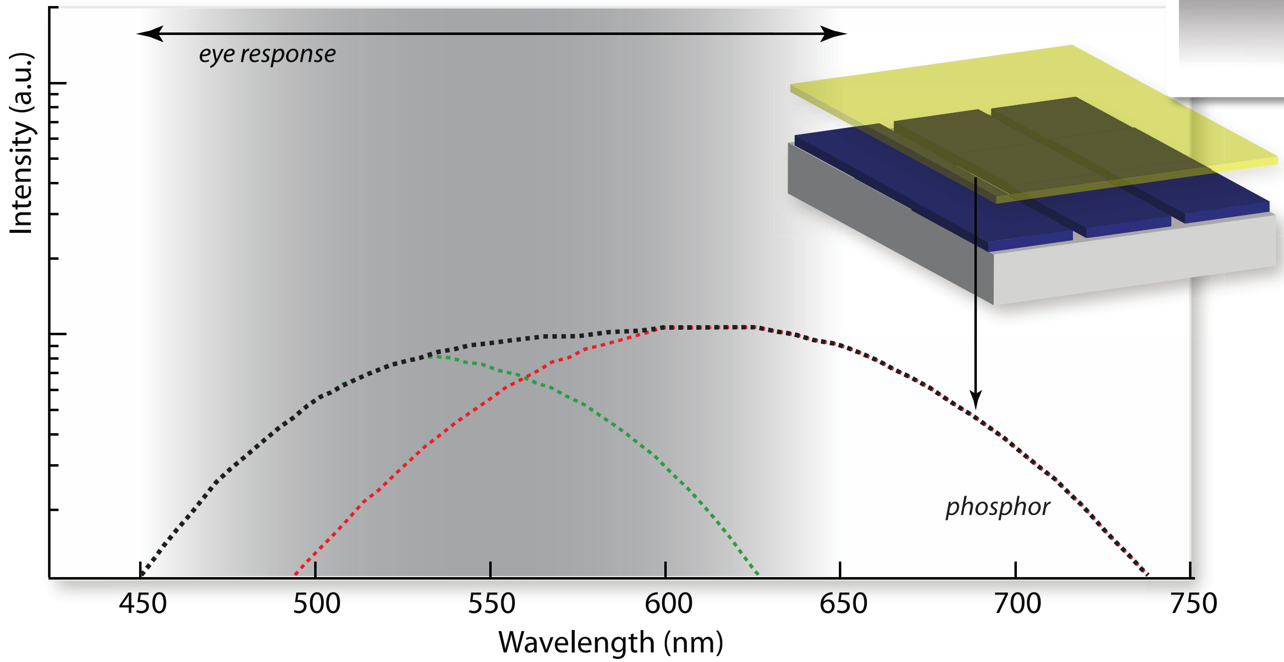
How LEDs Work: *Monochromatic Light*



How LEDs Work: *White Light*

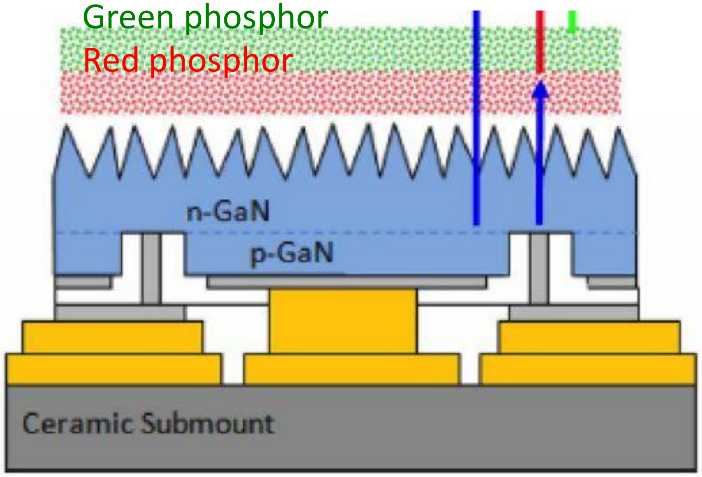
Today's design:

Blue LED + phosphors



Phosphor Conversion: *Blue to White Light*

Performance is limited by several mechanisms:



Energy Losses

- Stokes shift associated with down conversion
  - 18% for green
  - 29% for red
- Scattering and absorption
  - 20% for red, green and blue

Spectral Output

- Broadband output is difficult to tailor.
- Dynamic color control is not possible on a single chip.

J. Tsao, M.E. Coltrin, M.H. Crawford, J.A. Simmons, *Proceedings of the IEEE*, **98**, 1162 (2010)

How LEDs Work: *White Light*

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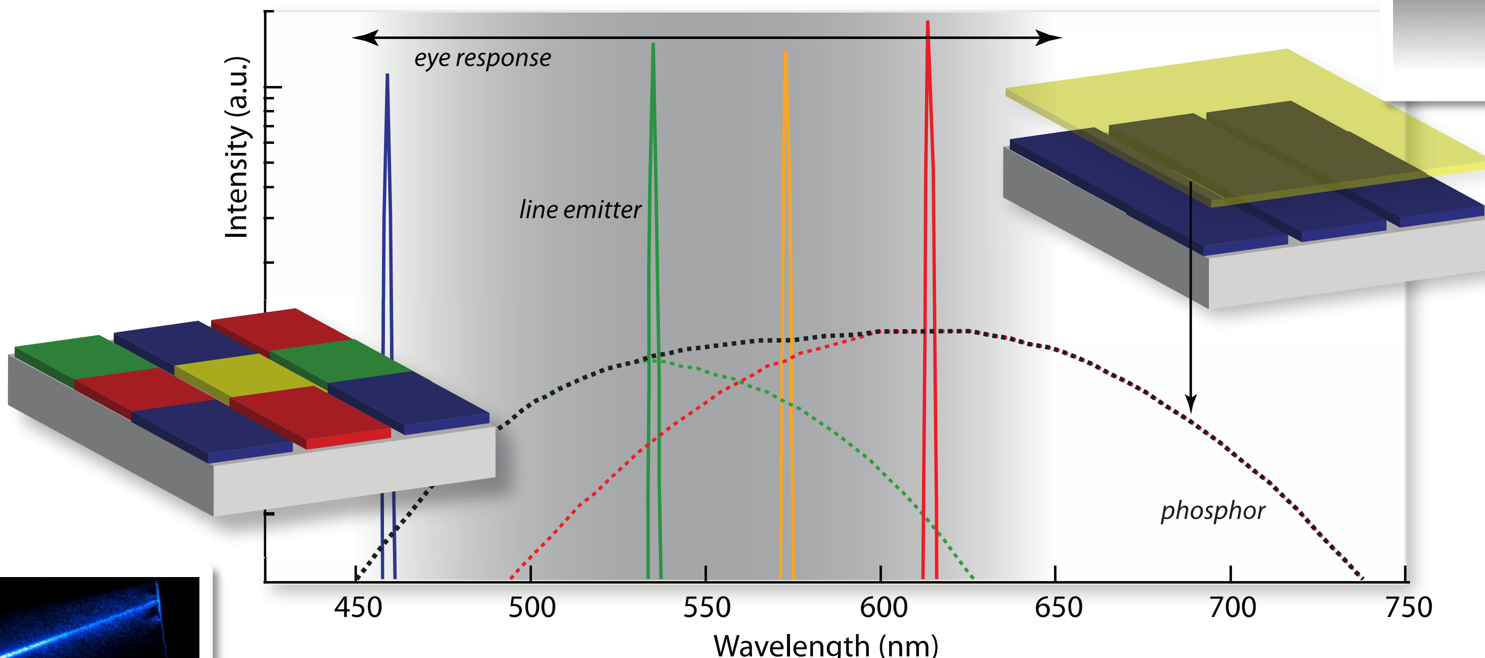
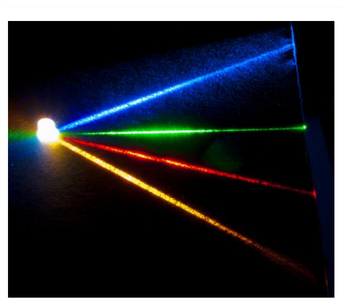


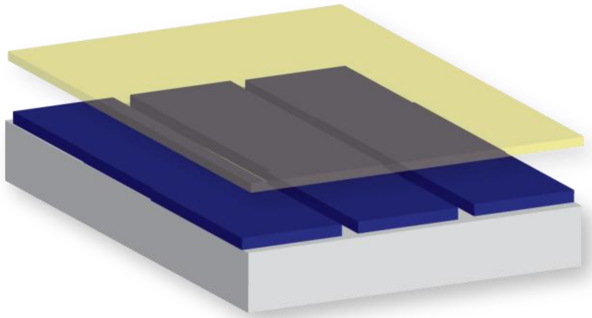


Tomorrow's design:
Combination of individual LEDs
to enable high efficiency *lighting* technologies

LEDs for Solid-State Lamps

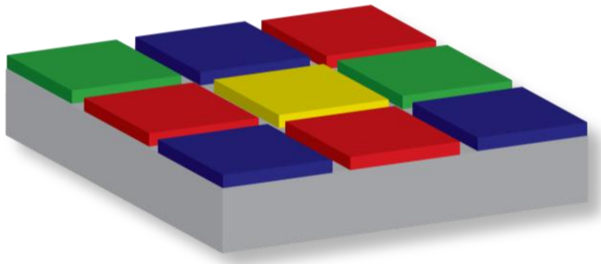
Today's design:
Blue LED + phosphors

- Prevalent approach in commercial devices
- CRI < 92 (***limited)***
- Efficiency limited by Stokes loss



Tomorrow's design:
RGB/RGBA

- 3- or 4-color LED approach
- CRI > 95 (***possible)***
- No Stokes loss
- ***This approach requires each of the LEDs also be highly efficient.***



Amber LEDs = Technical Game Changer

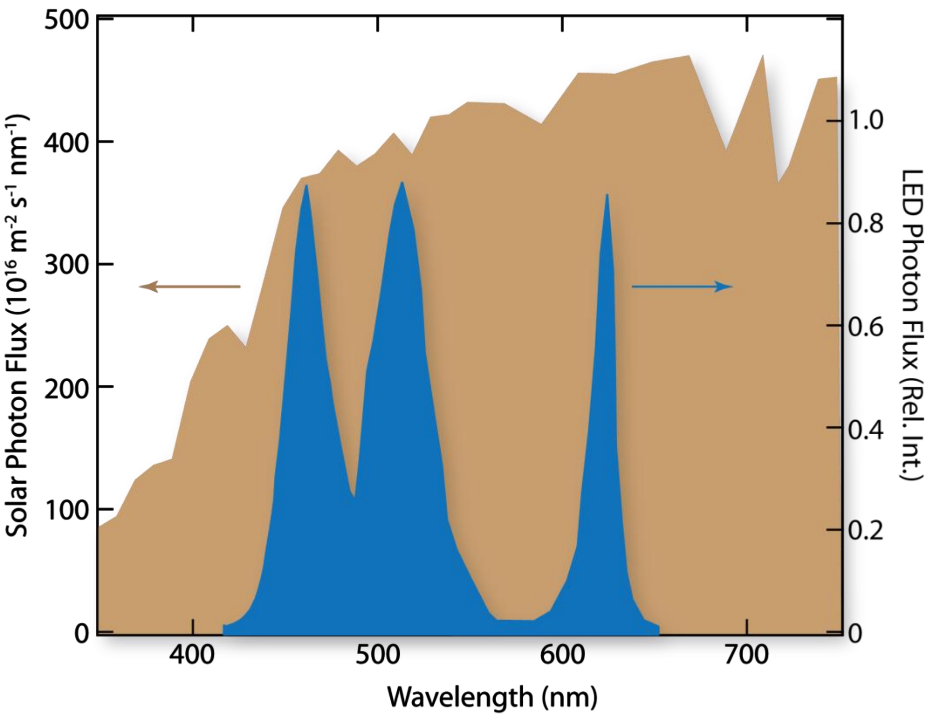
Creating white light through color mixing

The ability to render colors is an important characteristic of a light source

Source: Yoshi Ohno and Cameron Miller, National Institute of Standards and Technology, DOE SSL R&D Workshop 2013

Amber LEDs = Technical Game Changer

Creating white light through color mixing



Solar spectrum covers all visible wavelengths

- High energy use
- High CRI

RGB LEDs are missing a large region of the visible spectrum

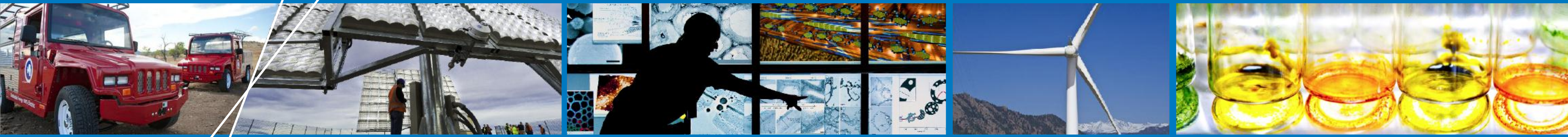
- Lower energy use
- Low CRI

The challenge:

Overcoming the obstacles to achieving highly ***efficient*** amber LEDs

Amber LEDs for Solid-State Lighting:

White light with unprecedented efficiencies



Limitations NREL's Technology Addresses

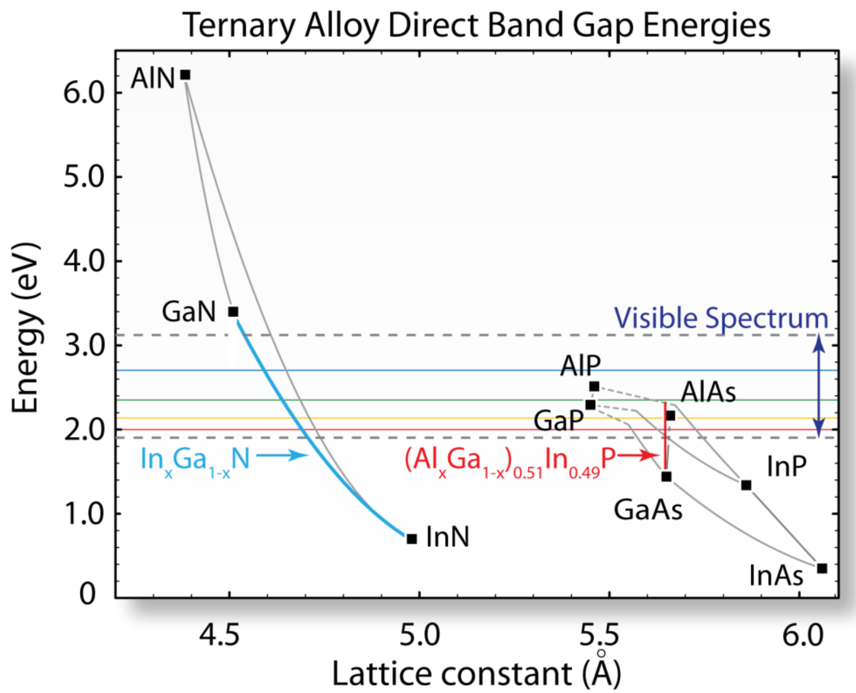
Conventional Materials for Visible LEDs

$In_xGa_{1-x}N$

- Suitable for short λ emission
- Addition of In reduces EQE

$(Al_xGa_{1-x})_{0.51}In_{0.49}P$ (AlGaInP)

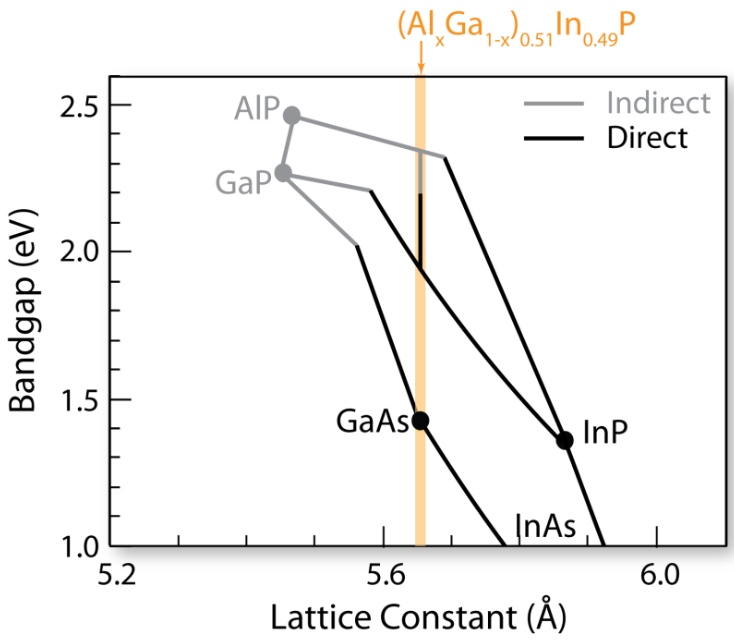
- Lattice-matched to GaAs
- Cannot reach high efficiencies at amber/green λ due to fundamental material issues

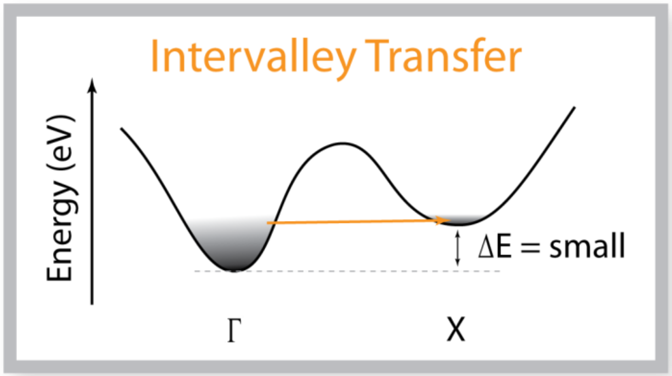


Color	Wavelength (nm)	Material	Current EQE @ 35 A/cm^2	2020 Target EQE
Blue	440-460	InGaN	75%	81%
Green	520-540	InGaN	32%	
Amber	580-595	AlGaInP	11%	
Red	610-620	AlGaInP	64%	

Loss Mechanisms in AlGaInP: Intervalley Transfer

Loss of electrons to indirect conduction band minima reduce the radiative recombination rate and emission efficiency



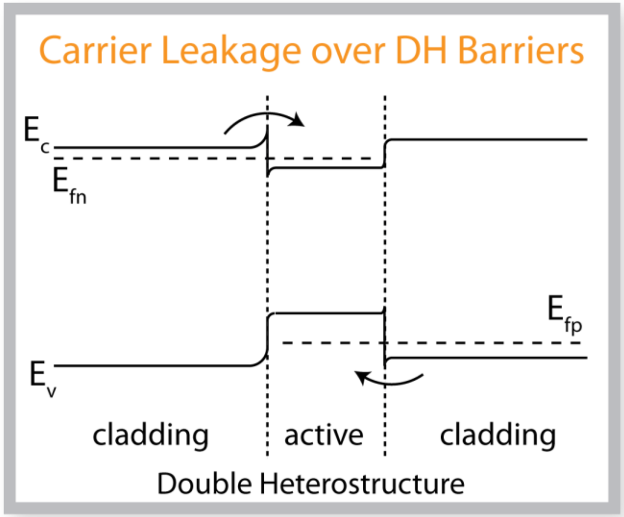


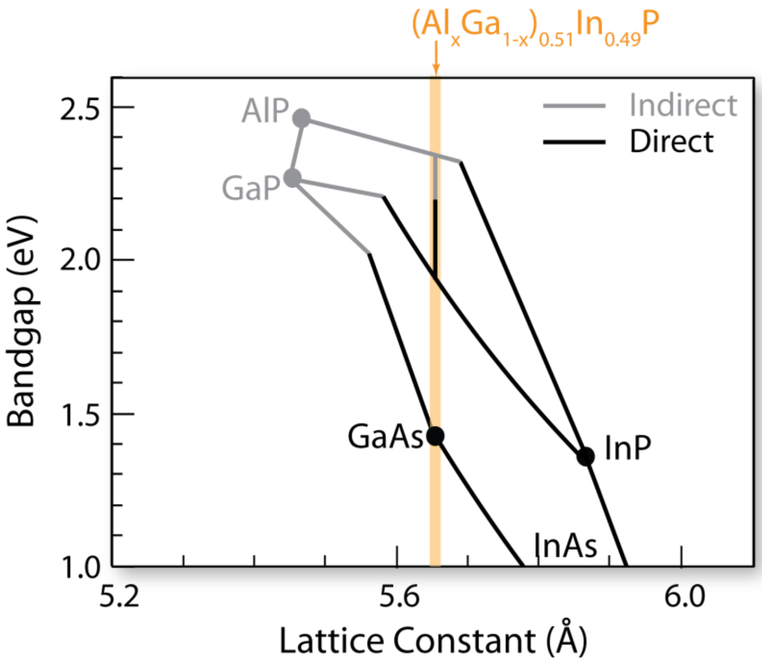
- $(Al_xGa_{1-x})_{051}In_{0.49}P$ undergoes a crossover at $x \sim 0.53$ (2.23 eV)
- Emission wavelength is limited to $\lambda > 582$ nm

  Assumes the Γ conduction band edge must be > 100 meV below the X edge.

Loss Mechanisms in AlGaInP: Carrier Leakage

The lack of a lattice-matched alloy to provide carrier confinement in the active layer leads to excessive carrier leakage from the LED.





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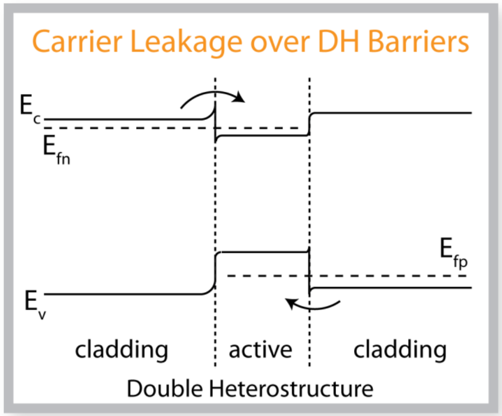
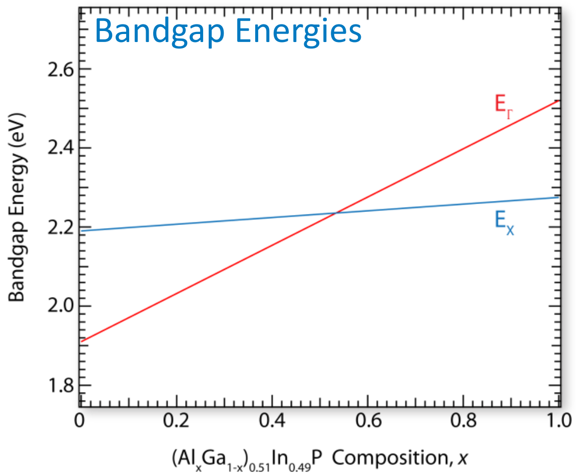
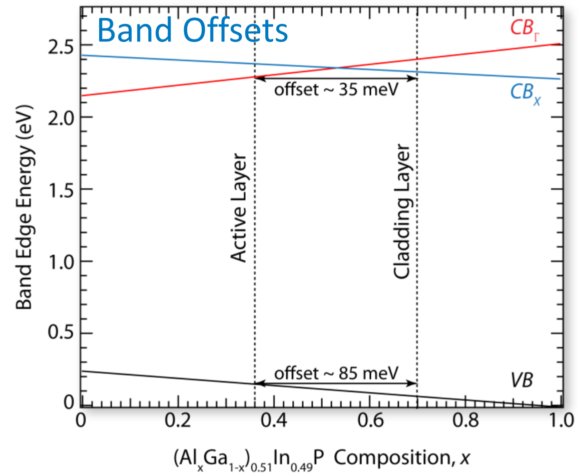


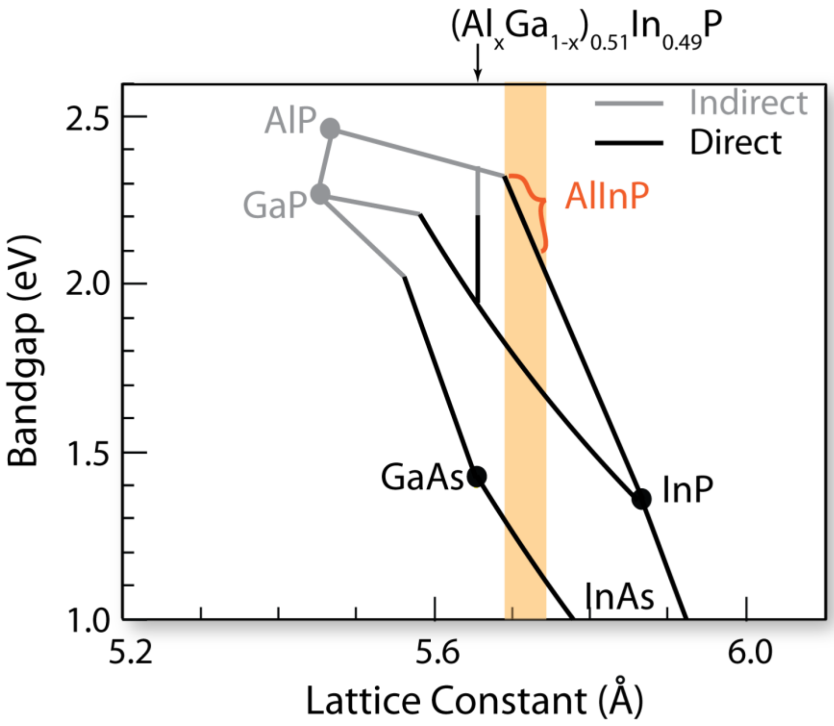


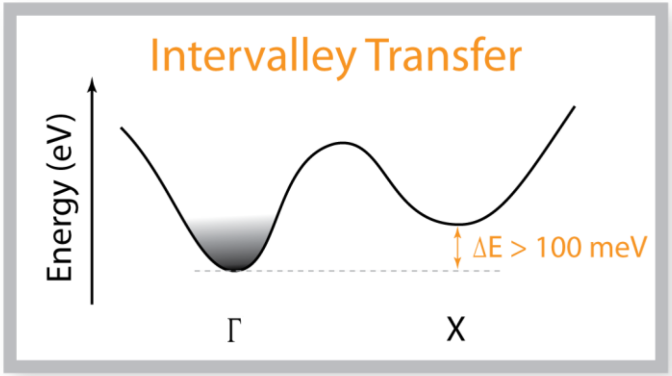


- Valence and conduction band offsets matter as much as total bandgap offsets.
- Traditional cladding layer designs do not provide adequate electron confinement.

AlInP for Amber LEDs

The use of AlInP for the active and cladding layers can reduce the impact of loss mechanisms.





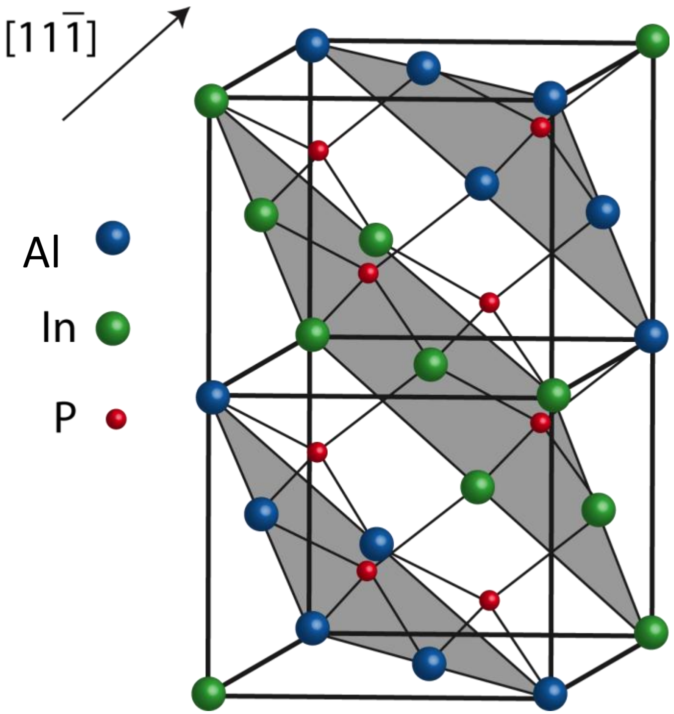
AlInP has the highest Γ-X crossover of any non-nitride III-V alloy.

Material	Crossover	Emission λ Limit
AlGaInP	2.23 eV	582 nm
AlInP	2.32 eV	558 nm

Cladding Layers: *New Engineering, Materials*

Control of spontaneous atomic ordering

Used to tune the conduction band edge of AlInP in order to create electron confinement in DHS devices.



T.M. Christian, *et. al. J. Appl Phys.* **114**, 074505 (2013)

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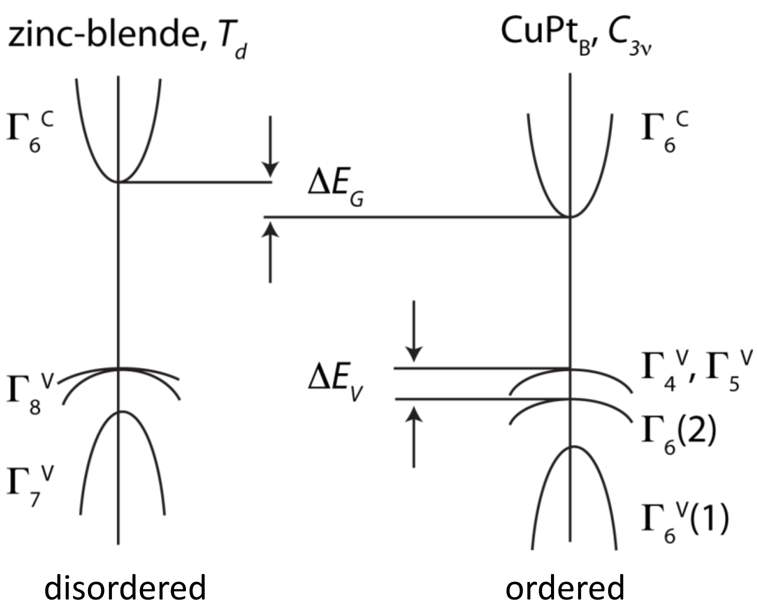
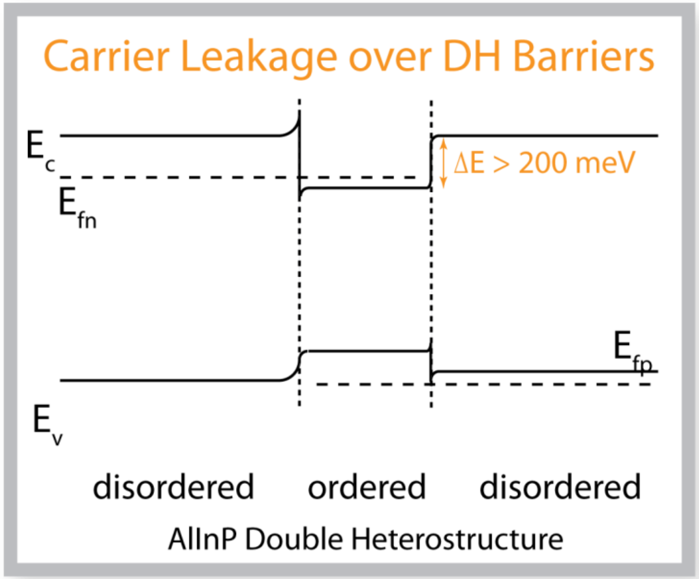




T.M. Christian, *et. al. J. Appl Phys.* **114**, 074505 (2013)

Cladding Layers: *New Engineering, Materials*

Control of spontaneous atomic ordering

- Partial ordering in AlInP causes a > *200 meV* drop in the Γ conduction band edge.
- Ordering is controlled during growth with substrate temperature and doping.
- Disordered/ordered/disordered AlInP DHS LEDs have built-in electron confinement without the need to change the alloy composition through the device layers.

T.M. Christian, *et. al. J. Appl Phys.* **114**, 074505 (2013)

Overcoming Past Production Barriers

A number of problems had previously prevented the use of AlInP as the light-emitting material in LEDs.

Oxygen contamination

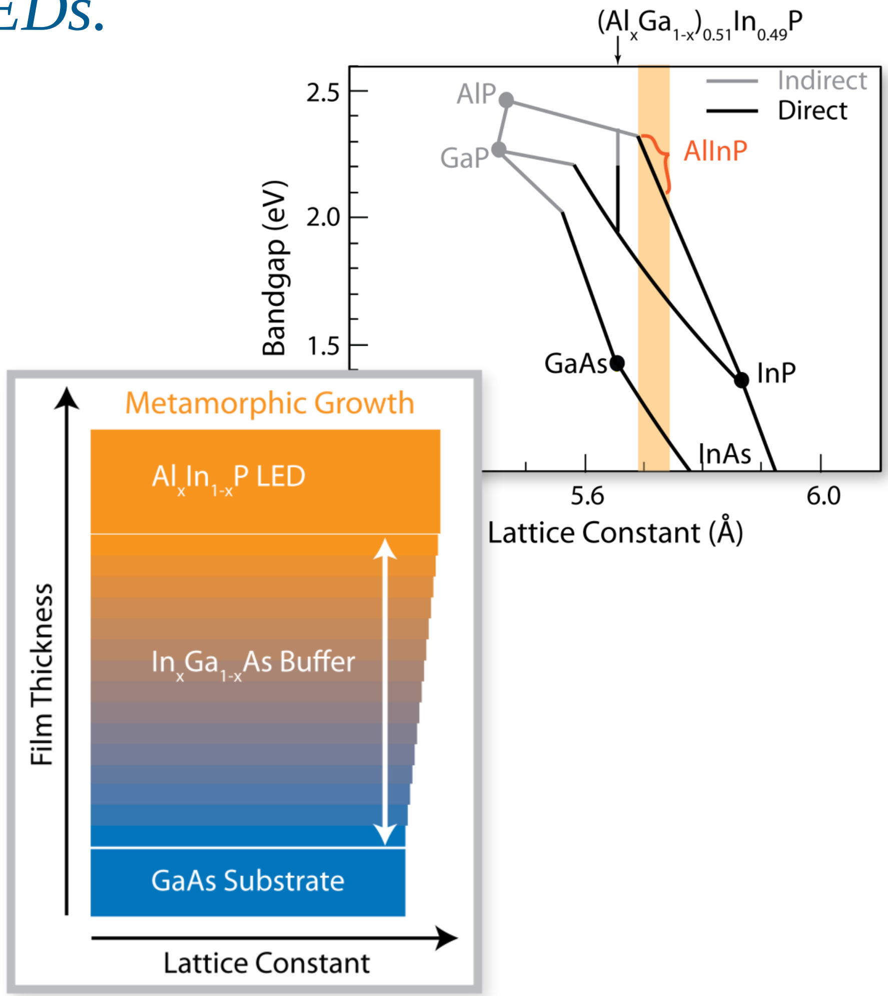
- Oxygen bonds very strongly to Aluminum.
- Oxygen impurities reduce radiative recombination efficiencies.
- Improvements in reactor design and precursor purity have reduced this problem.

Overcoming Past Production Barriers

A number of problems had previously prevented the use of AlInP as the light-emitting material in LEDs.

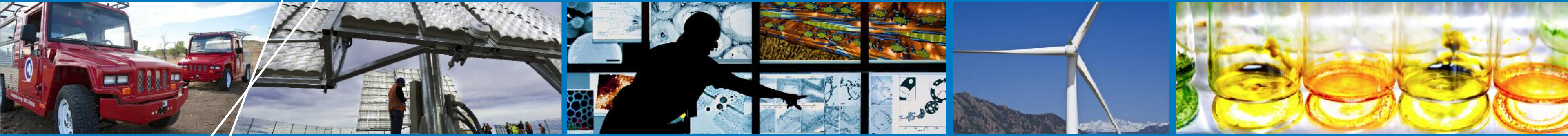
Lattice-mismatch

- The growth of AlInP with a compositionally graded buffer accommodates the lattice-mismatch to GaAs.
- Buffer ~ 1-2 μm thick
- Threading dislocation density ~ $10^4 – 10^5$ cm^{-2}



Amber LEDs for Solid-State Lighting:

White light with unprecedented efficiencies

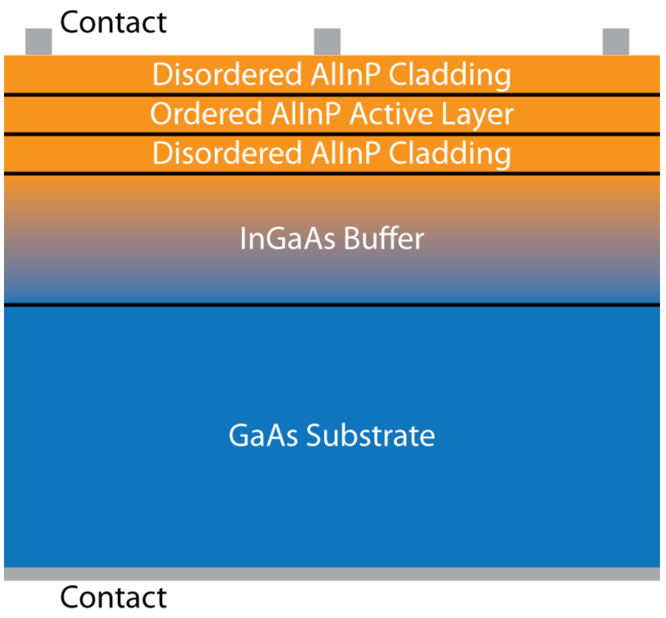


Performance Testing Results

AlInP LED Performance

AlInP and AlGaInP LEDs were compared to red-emitting lattice-matched $Ga_{0.5}In_{0.5}P$ LED standards of the same structure in order to gauge relative efficiency.

- No need for an optimized LED structure with current spreading and light extraction.



T.M. Christian, *et. al. J. Appl Phys.* **114**, 074505 (2013)

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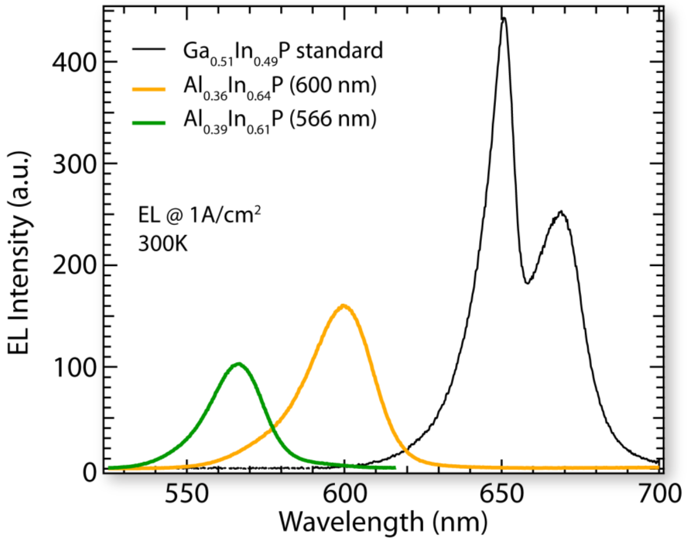
- No need for an optimized LED structure with current spreading and light extraction.
- Extrapolation to optimized absolute efficiencies:
  - Lattice-matched $Ga_{0.5}In_{0.5}P$ LED has > 50% EQE
  - Our best $Al_xIn_{1-x}P$ LED (595 nm) is 39% as efficient as the $Ga_{0.5}In_{0.5}P$ standard.



T.M. Christian, *et. al. J. Appl Phys.* **114**, 074505 (2013)

AlInP LED Performance: *2X efficiency!*

These results suggest that our AlInP LEDs could have absolute EQEs as high as 20%.

Amber LED Efficiency Comparison

Material	Efficiency
AlGaInP	10%
AlInP	**20%** (extrapolated)

AlInP Amber LEDs could be twice as efficient as conventional AlGaInP technologies.

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Amber LED Efficiency Comparison

Material	Efficiency
AlGaInP	10%
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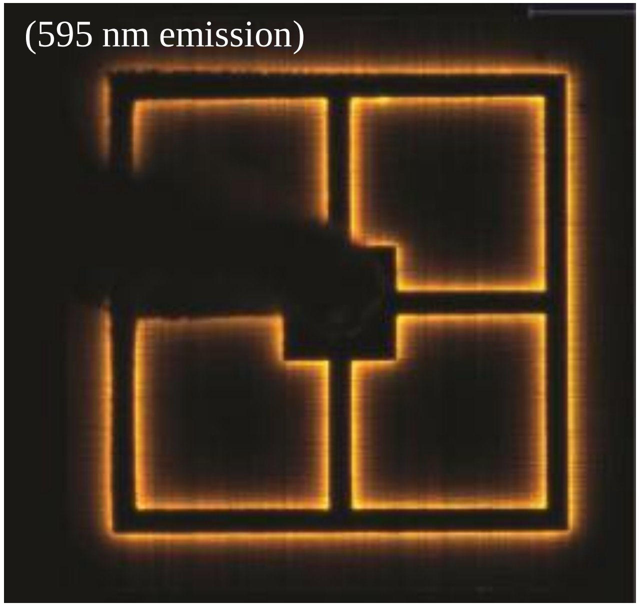
AlInP Amber LEDs could be twice as efficient as conventional AlGaInP technologies.

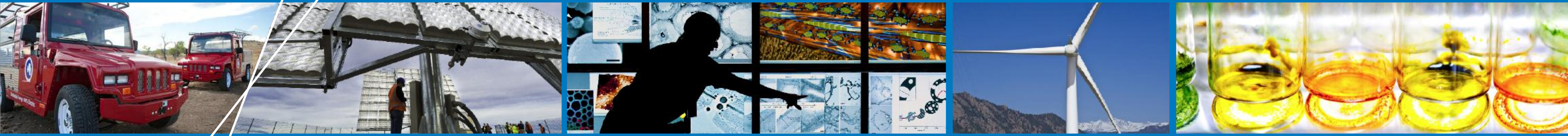
Further advances can be made with improvements to material quality and carrier confinement



AlInP LED Actual Photo

Amber LEDs for Solid-State Lighting:

White light with unprecedented efficiencies



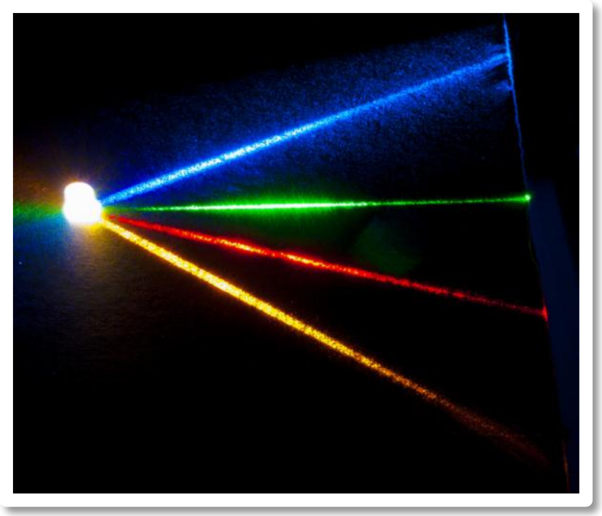
Summary of Benefits/Advantages

Conventional vs. NREL Amber LED

Figure of Merit	AlGaInP (Conventional)	AlInP (NREL)
Lattice Matching to GaAs	Matched	Mismatched (< 1%)
Dislocation Density	$10^3 – 10^4$ cm^{-2}	$10^4 – 10^5$ cm^{-2}
Direct-Indirect Bandgap Crossover	2.23 eV	2.32 eV
Intervalley Transfer Limit	582 nm	558 nm
Electron Confinement	< 80 meV	> 200 meV
Efficiency (current state-of-the-art)	11% (absolute)	20% (extrapolated)

Conventional vs. NREL Amber LED

*NREL's AlInP amber LED technology will enable color-mixing **RGBA** white LED architectures.*



Advantages of NREL Approach

Performance advantages

- Higher Γ-X crossover and electron confinement in ordered/disorderd heterostructures allow AlInP LEDs to ***outperform*** AlGaInP LEDs at wavelengths < 600 nm
- ***Twice the efficiency*** of other amber LEDs

NREL's Amber LED

Advantages of NREL Approach

Manufacturing advantages

- Can be grown on ***conventional*** GaAs substrates
- Utilize the ***same manufacturing process*** as the AlGaInP LEDs currently produced by industry
    - MOCVD growth process
    - Similar DHS device structure.

NREL's Amber LED

Commercialization Opportunity

- Applications for the Technology
- Market Opportunity
- Intellectual Property
- Licensing Process
- Other Opportunities

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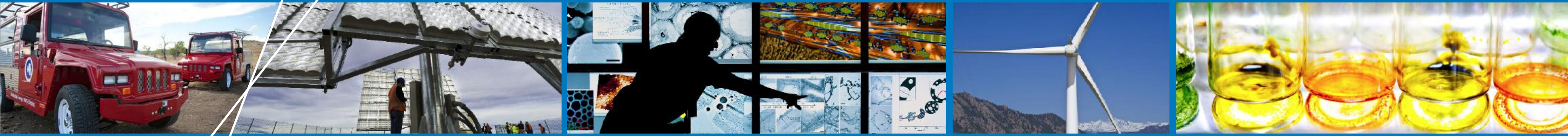
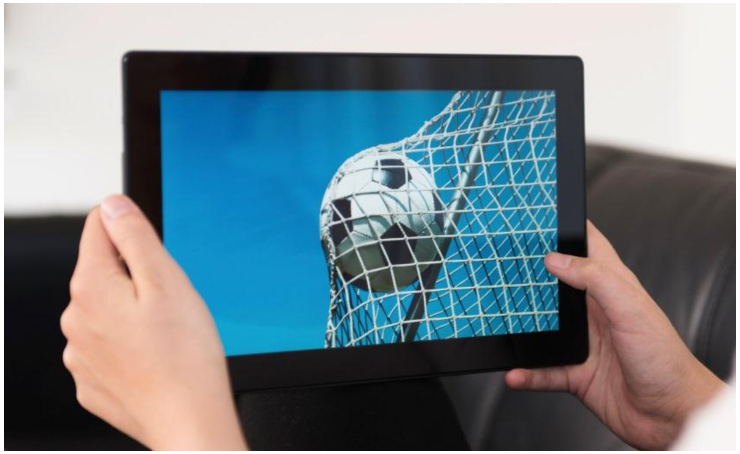


Applications for the Technology

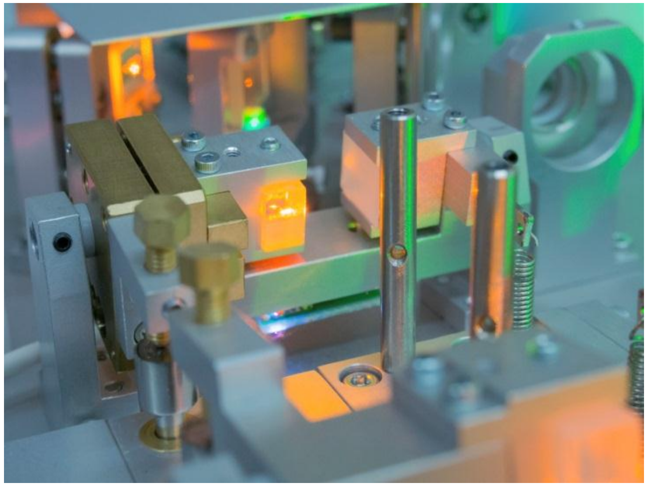
Applications for the Technology

Solid-State Lighting



Applications for the Technology

- Photovoltaics
- Lasers



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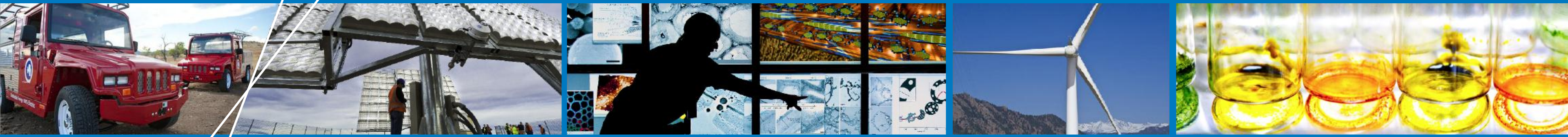


Market Opportunity

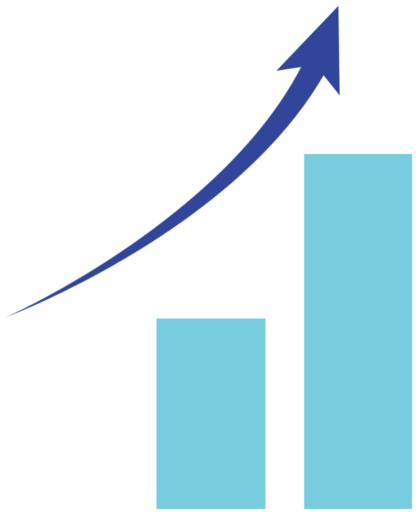
Market Opportunity

- **87% of SSL in 2012 was backlighting/general lighting**
  - High growth expected
- **Global distribution of SSL market**

Source: Ibid

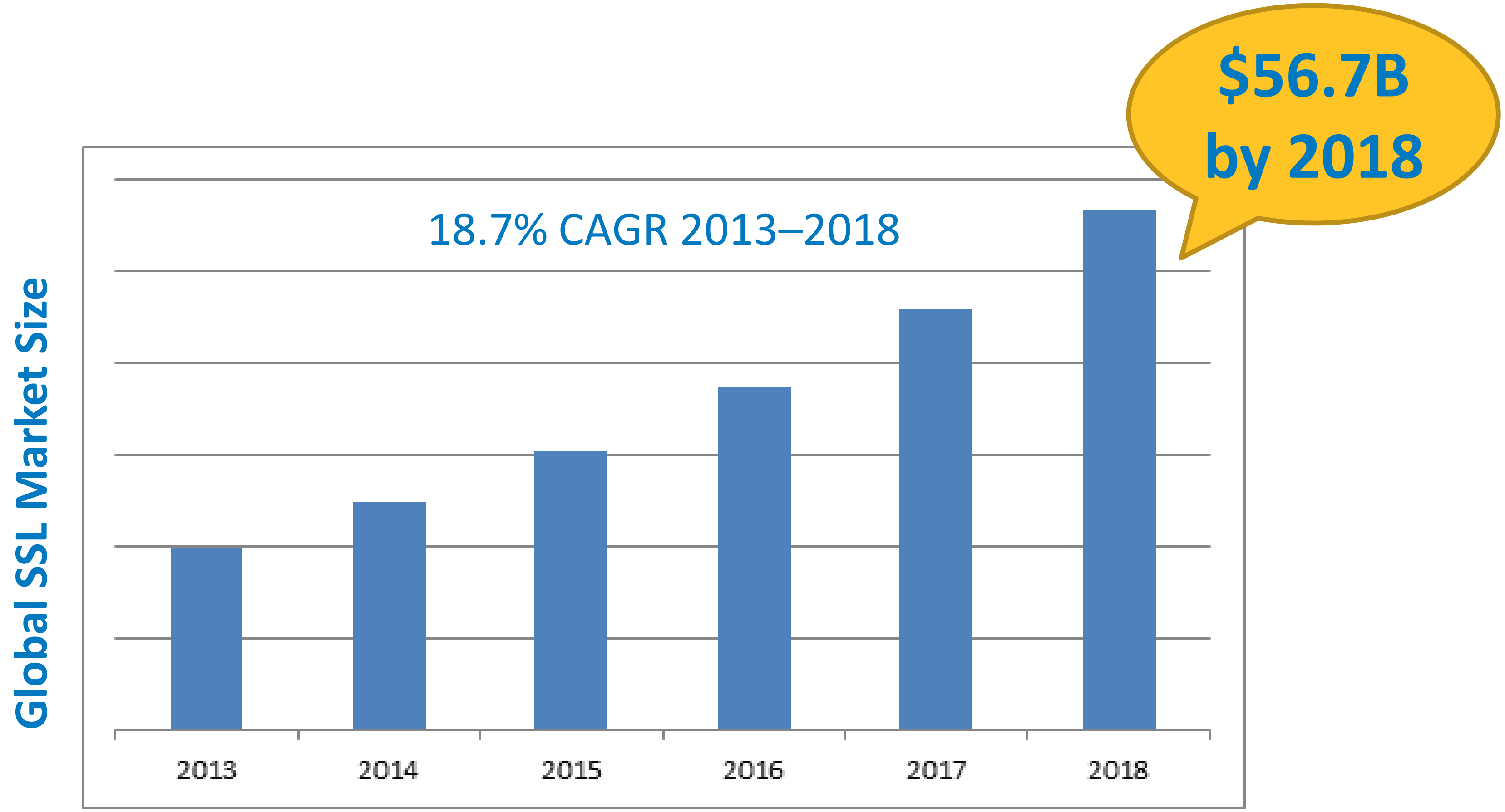
Market Opportunity

- **$35.3B LED lighting market by 2014**
  - 47.8% growth over 2013



Source: LEDinside.com, "TrendForce: Global LED Lighting Demand Growths to Continue in 2014," published Oct. 15, 2013

Market Opportunity



Source: MarketsandMarkets, "Solid State Lighting Market by Types (LED, OLED, and PLED), Application (General Lighting, Backlighting, Automotive, Medical), Verticals (Industrial, Residential, Consumer Electronics), Materials & Geography - Analysis & Forecast (2013-2018)" published September 2013

Amber LEDs = Market Game Changer

- LED lighting is a huge, high-growth market

- NREL's technology

=

Better LED-based white light SSL

- More efficient
- Easy to manufacture
- Dynamic color control
- Low-cost materials

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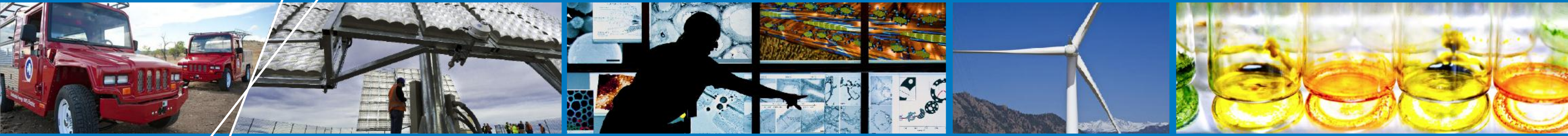
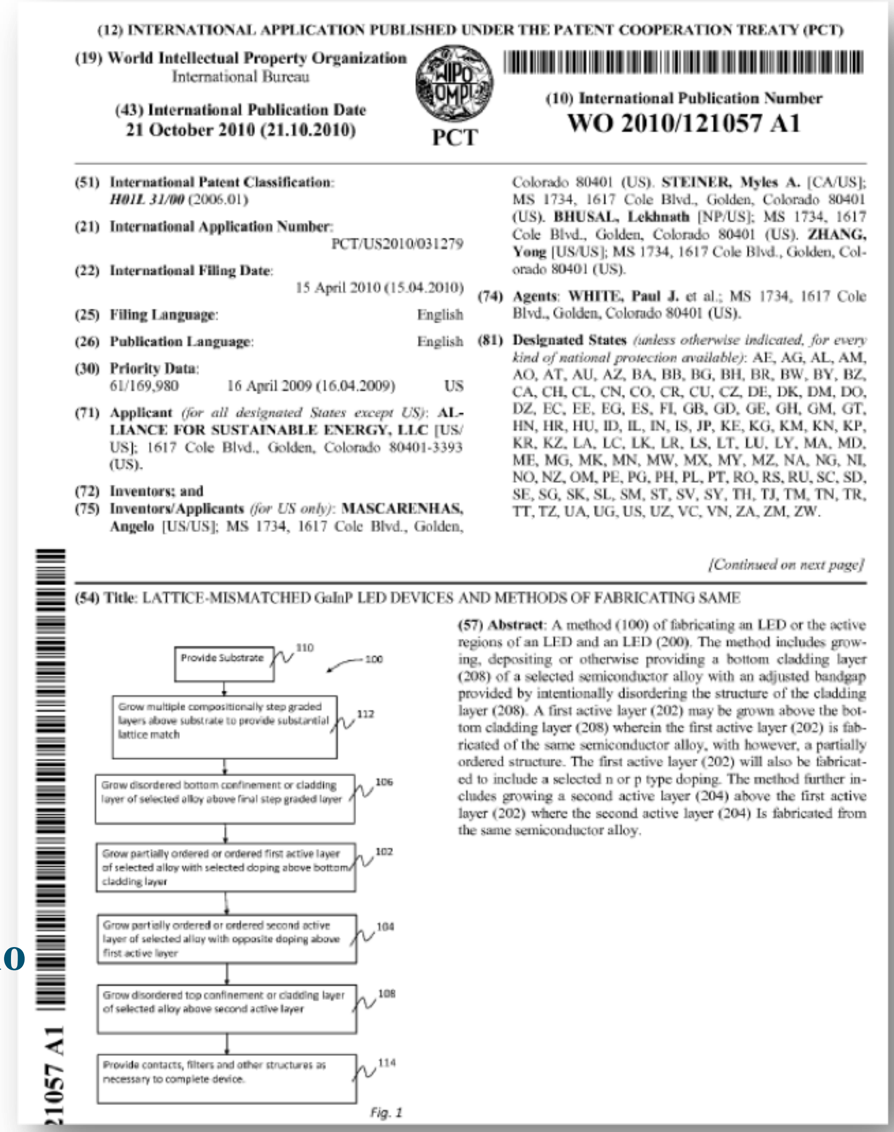


Intellectual Property

Intellectual Property

- Record of Invention (ROI) 09-36: Patent application pending in US
- ROI 10-64: Patent application pending in US, Canada, Japan, and Europe

Patents accessible at: http://www.nrel.gov/technologytransfer/technologies_led.html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(25) Filing Language: English

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(81) Designated States (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

[Continued on next page]

(54) Title: LATTICE-MISMATCHED GaInP LED DEVICES AND METHODS OF FABRICATING SAME

Provide Substrate 110
100
Grow multiple compositionally step graded layers above substrate to provide substantial lattice match 112
Grow disordered bottom confinement or cladding layer of selected alloy above final step graded layer 106
Grow partially ordered or ordered first active layer of selected alloy with selected doping above bottom cladding layer 102
Grow partially ordered or ordered second active layer of selected alloy with opposite doping above first active layer 104
Grow disordered top confinement or cladding layer of selected alloy above second active layer 108
Provide contacts, filters and other structures as necessary to complete device. 114
Fig. 1

(57) Abstract: A method (100) of fabricating an LED or the active regions of an LED and an LED (200). The method includes growing, depositing or otherwise providing a bottom cladding layer (208) of a selected semiconductor alloy with an adjusted bandgap provided by intentionally disordering the structure of the cladding layer (208). A first active layer (202) may be grown above the bottom cladding layer (208) wherein the first active layer (202) is fabricated of the same semiconductor alloy, with however, a partially ordered structure. The first active layer (202) will also be fabricated to include a selected n or p type doping. The method further includes growing a second active layer (204) above the first active layer (202) where the second active layer (204) is fabricated from the same semiconductor alloy.

WO 2010/121057 A1

Amber LEDs for Solid-State Lighting:

White light with unprecedented efficiencies

Licensing Process

Technology Transfer Office Role

- Manages commercialization of the Intellectual Property (IP) Portfolio
- Negotiates patent and software licensing agreements
- Negotiates terms for technology partnership agreements (CRADA, WFO, TSA etc.)
- Encourages innovation and entrepreneurship
- Provides commercialization assistance

NREL Licensing Agreement Process

Dec. 10	LED Technology Briefing Webcast
Dec. 12 - Jan. 17	One-on-One Discussions
Feb. 10	License Application
Feb. 20	Selection of Partners
Feb. 28	Negotiation of Term Sheet Begins
	NREL Develops Draft License Agreemen
	Negotiate License Language
	Execute License
	NREL/Partner Manage Commitment

1-on-1 Private Conversations – *Thru Jan. 17*

- Present company-specific information
- Ask questions

This is a non-confidential discussion (no NDAs signed)

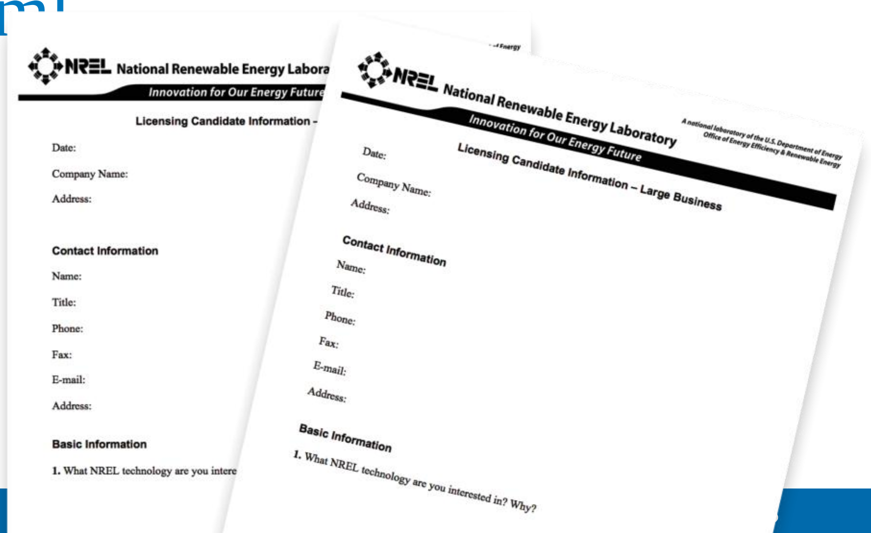
To Request a Meeting
Complete brief "survey" after live webinar
or
https://nrel.acuityscheduling.com

License Application – *Due Feb. 10*

WHAT

Licensing Candidate Information Form

- Less than a business plan, more than a term sheet
- Templates at http://www.nrel.gov/technologytransfer/licensing_agreements.html
  - Small Business
  - Large Business



License Application – *Due Feb. 10*

WHAT

Licensing Candidate Information Form

WHY

Evaluate Impact

- Benefits for NREL, company, taxpayers
- Only a few can be selected, limited inventor availability

License Application – *Due Feb. 10*

WHAT	Licensing Candidate Information Form
WHY	Evaluate Impact
WHO	Serious Candidates Only

License Application – *Due Feb. 10*

WHAT	Licensing Candidate Information Form
WHY	Evaluate Impact
WHO	Serious Candidates Only
WHEN	Due Feb. 10

- All offers evaluated at the same time
- Maximize benefits through simultaneous, strategic selection

Application Contents

Licensing Candidate Information Form

- **Company background**
  - Product or service to use technology
  - Market size
    - Current and potential with addition of this technology
  - Capabilities
    - Technical, management, marketing, and financial
  - Requirements from NREL

Application Contents

Licensing Candidate Information Form

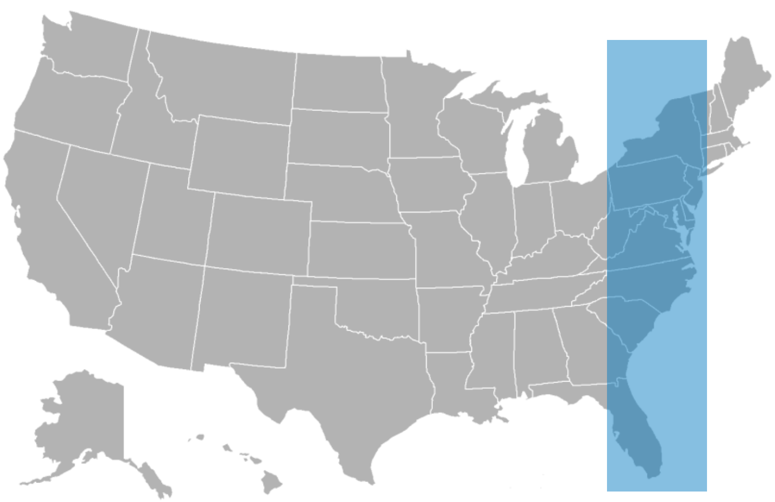
- **Company background**
- **Appendices**
  - Key personnel résumés
  - Term sheet
  - Pro forma income – *form provided*

Term Sheet – *Snapshot*

- Outline basic offer
- Specify type of license
- Propose fees and royalties
- Establish schedule and key milestones

Term Sheet

- **Outline basic offer**
  - Fields of use, period of time, or geographic area
    - Limit to areas licensee intends to market
  - Highlight any significant terms or conditions



Term Sheet

- **Outline basic offer**
- **Specify type of license**
  - Exclusive, partially exclusive, non-exclusive

Types of Licenses

- **Exclusive or partially exclusive**
  - Must be substantially manufactured in the US for products sold in US
  - Allows sub-licensing
  - Patent cost reimbursement

License agreement guidance available online:

http://www.nrel.gov/technologytransfer/licensing_agreements.html

Types of Licenses

- **Exclusive or partially exclusive**
- **Non-exclusive**
  - No sub-licensing
  - No US manufacturing requirement
  - Pro-rated patent cost reimbursement
  - Multiple licensees

License agreement guidance available online:
http://www.nrel.gov/technologytransfer/licensing_agreements.html

Term Sheet

- **Outline basic offer**
- **Specify type of license**
- **Propose fees and royalties**
  - Upfront fee, patenting costs, running royalty

Fees and Royalties

- **Upfront fee**
  - Due 30 days after license execution
- **Patenting costs**
- **Running royalty**
  - Paid at least annually
    - Based on Net Sales (see license agreement definition)
    - Specify preferred metric (e.g., units)
    - Ascending/Descending royalty structure
  - Minimum annual royalties
  - Non-royalty sublicensing payments – *exclusive*

Term Sheet

- Outline basic offer
- Specify type of license
- Propose fees and royalties
- Establish schedule and key milestones

Schedule and Key Milestones

- **Annual reports**
- **Milestone examples**
  - Prototype demonstration
  - Manufacturing process development
  - Funding/Investments (especially for start-ups)
  - Marketing of product
  - Achievement of sales

Application Contents

Licensing Candidate Information Form

- **Company background**
- **Appendices**
  - Key personnel résumés
  - Term sheet
  - Pro forma income – *form provided*

Pro Forma Income Statement

- 3 years
- Only for the product line using NREL's technology
- Royalty payments and minimums
- Clear assumptions

Submit in electronic format only
MS Excel preferred

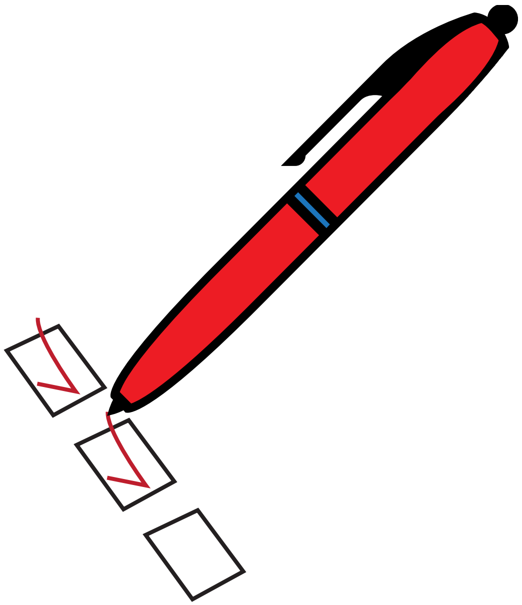
Sample Pro Forma Income Statement

1	Instructions: Please use this Pro Forma template in support of Part 1 of the license application.					
2	Complete only the green shaded boxes. All other values will be calculated from your inputs.					
3	Product:	ABC			Royalty Rate Structure	Annual rate inc. or dec.
4					Starting Royalty Rate	7.0%
5					Annual Change in Royalty Rate (Increase or Decrease)	1.0%
6	Percentage of Product Attributable to Licensed Technology:	80.0%				
7	Discount / Risk Rate	7.0%				
8	Company Financials	Year 1	Year 2	Year 3		
9	Revenue					
10	Price per Unit	$5,000	$5,000	$5,000	Repeat sections for each varied product types	
11	Units Sold	600	720	864		
12	Projected Sales	$3,000,000	$3,600,000	$4,320,000		
13	Expenses					
14	Cost of Goods Sold	$1,500,000	$1,800,000	$2,160,000		
15	Selling, General & Admin. Expenses	$750,000	$900,000	$1,080,000		
16	R&D Costs	$200,000	$200,000	$150,000		
17	Total Expense	$2,450,000	$2,900,000	$3,390,000		
18	Pre-Licensing Fee Margins					
19	Net Profit	$550,000	$700,000	$930,000	Sum all revenues – Sum all expenses	
20	Gross Margin (%)	18.3%	19.4%	21.5%		
21	Licensing Fees					
22	Up Front Licensing Fee	$200,000				
23	Royalty Rate	7.00%	7.07%	7.14%		
24	Royalty Payment	$210,000	$254,520	$308,478		
25	Minimum Annual Royalty Payment	$100,000	$200,000	$300,000		
26	Actual Royalty	$410,000	$254,520	$308,478		
27	Cumulative NPV of Royalty Revenue	$410,000	$605,485	$857,295		

Current values are for example only. Please provide accurate and appropriate estimates for your company and product offering.

Evaluation Criteria

- Technical
- Business
- Management
- Economic



Not all qualified companies will be granted a license

Submit your best offer

Negotiations – *finding the win-win*

- **Negotiable**
  - Type of license
  - Field of use
  - Upfront licensing fee
  - Running royalty rate
  - Yearly minimums
  - Milestones

Negotiations – *finding the win-win*

- Negotiable
- **Non-negotiable**
  - NREL/Gov't retains irrevocable, royalty-free rights to technology for noncommercial uses
  - Flow-down provisions from NREL's Prime Contract with the U.S. Department of Energy
  - Bayh-Dole requirements
  - Indemnity and warranty

More about NREL requirements:
http://www.eere.energy.gov/golden/NREL_Prime.aspx
Download Section I (Contract Clause) & search for "technology transfer"

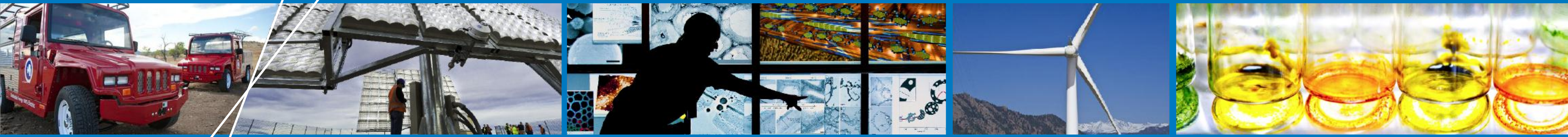
Signature and Monitoring

- **Signing the agreement**
  - Selected companies announced after signature
- **Monitoring commercialization**
  - Ensuring milestones met
  - Compliance with annual reporting and payments
  - Success points will be celebrated and publicized with the support of NREL Public Affairs

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Amber LEDs for Solid-State Lighting:

White light with unprecedented efficiencies



Other Opportunities

Other Opportunities

- **Related IP**
- **Collaborative R&D**
- **Use of NREL labs**
  - Work for Others
  - User Facility

Other IP Relevant to the Market

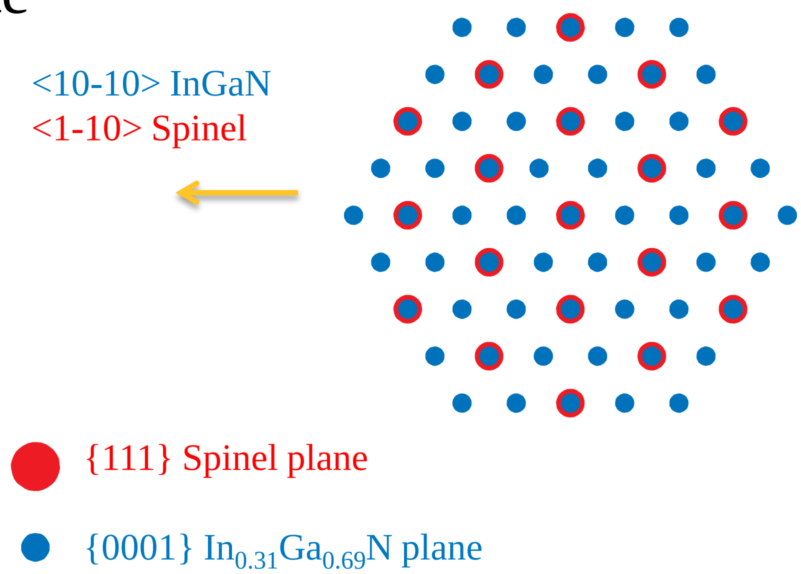
- **Growth of Lattice-Matched Semiconductor Layers**
  - ROI 08-34, 08-40, 08-60, 10-37, and 10-44
  - Better matching the orientations of semiconductor materials to increase yields, reduce costs, and make more efficient semiconductors

Other IP Relevant to the Market

Coincident-Site Lattice Matching of InGaN on Spinel Substrates

(0001) $In_{0.31}Ga_{0.69}N$ on (111) $MgAl_2O_4$ spinel:

- 30º rotation results in coincident-site lattice match condition
- Results in lower strain films

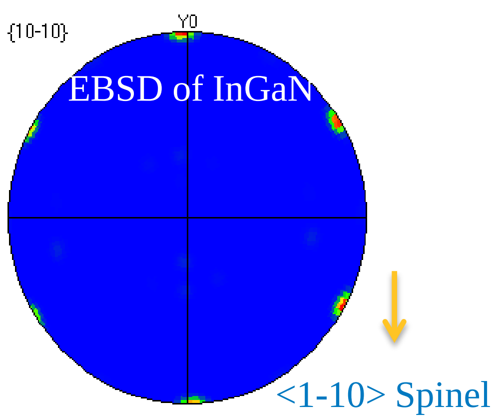


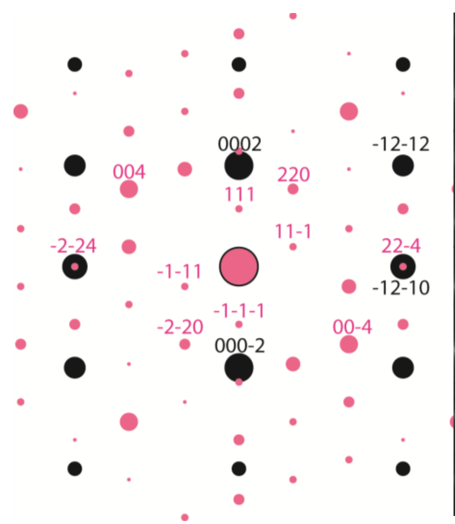
Other IP Relevant to the Market

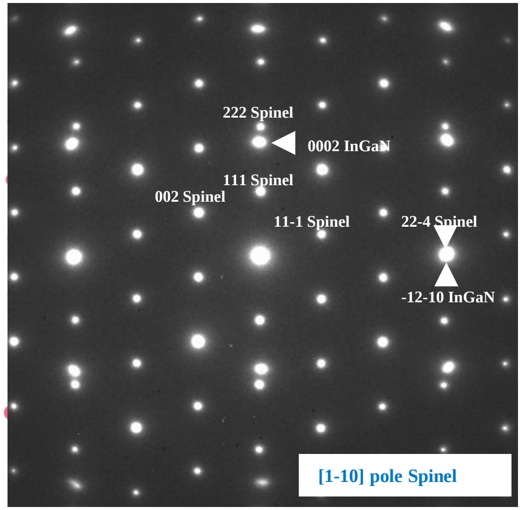
Coincident-Site Lattice Matching of InGaN on Spinel Substrates

$In_{0.31}Ga_{0.69}N$ films grown on spinel by MBE

- Nitride films show coincident-site lattice match rotation by electron backscatter diffraction (EBSD)
- Film rotation confirmed by transmission electron diffraction







Other IP Relevant to the Market

Coincident-Site Lattice Matching of InGaN on Spinel Substrates

- **Future Development**
- **In0.31Ga0.69N on spinel material studies needed**
  - Confirm coincident-site growth by MOCVD
  - Measure structural properties (assess strain, dislocation density, phase separation, if applicable)
- **Coincident-site lattice matched LED device development**
  - Development of quantum wells
  - Study optoelectronic properties
- **Ideal collaborator would have resources to do both material and device development of this technology**

Other IP Relevant to the Market

- **Multijunction Solar Cell (PV) Device**
  - ROI 09-59
  - Uses additional layers that bridge the gap between disparate-sized semiconductors to create highly efficient multijunction PVs

Partnering with NREL

- **NREL pursues funding opportunities with commercial partners**
- **Understand your needs so we can assess our capabilities**
  - Testing, validation, optimization, research

Lab Snapshot

- **Energy efficiency and renewable energy technology R&D**
  - 35+ years of accomplishments and market impact
  - $309M in FY13
  - 2,000+ staff

Lab Snapshot

- Energy efficiency and renewable energy technology R&D
- More than 350 active partnerships
- International benchmark for sustainability

Scope of Mission

Energy Efficiency

- Residential Buildings
- Commercial Buildings
- Personal and Commercial Vehicles

Renewable Energy

- Solar
- Wind and Water
- Biomass
- Hydrogen
- Geothermal

Systems Integration

- Grid Infrastructure
- Distributed Energy Interconnection
- Battery and Thermal Storage
- Transportation

Market Focus

- Private Industry
- Federal Agencies
- Defense Dept.
- State/Local Government
- International

PV Portfolio

- Black Silicon
- High Efficiency CdTe
- CIGS Solar Cells
- Electrical Calcium Test Method
- High-throughput Semiconductor Deposition Technique
- Lattice-mismatched Green LED
- Thermal Scout Software
- Thin-film CZTSS Fabrication Technique
- Transpired Solar Collector

Photos: (left to right) PIX 17852, PIX 15779

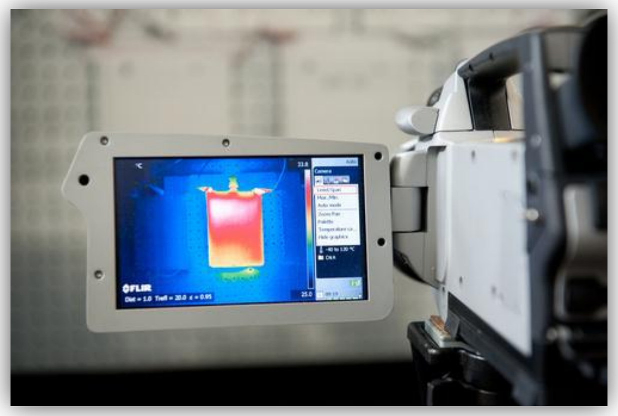
Biofuels Portfolio

- **Attrition Resistant Catalysts**
- **Bio-based Production of Ethylene**
- **Biomass Treatment**
- **Cellulase Production**
- **Endoglucanase**
- **Wet Chemical Composition**
- ***Zymomonas Mobilis 8b***

Photos: (left to right) PIX 17375, PIX 15644

Energy Generation and Storage Portfolio

- Binderless Electrodes
- Fail-safe Design for Large Capacity Li-ion Battery Systems
- Hybrid Radical Batteries
- Simultaneous Distribution of AC/DC Power



Photos: (left to right) PIX 22068, PIX 22021

Wind Portfolio

- **Airfoils**

Photos: (left to right) PIX 21924, PIX 10969

Vehicles Portfolio

- **Vehicle Component Heat Dissipation Improvements**

Photos: (left to right) PIX 20037, PIX 22731

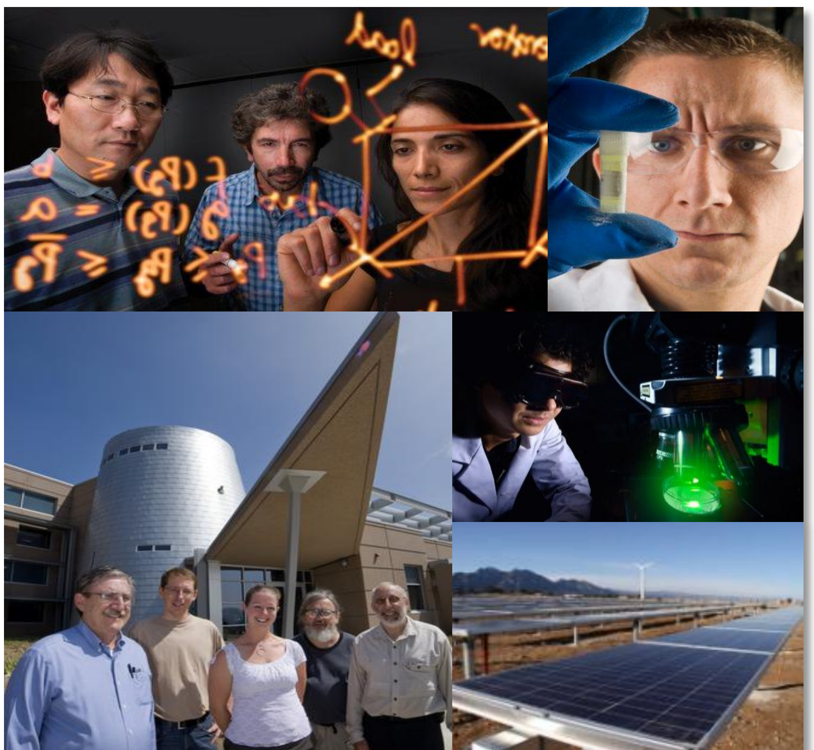
Buildings Portfolio

- **Augmented Reality Building Operations Tool**
- **Image Processing Occupancy Sensor**

Photos: (left to right) PIX 19350, PIX 17653

NREL Commercialization Assistance Program

- **Up to 40 hours of NREL assistance and information to help small businesses with technology challenges**



Examples of NCAP Assistance

- Test and measurement of systems or components
- Analytical testing of materials
- Insights on existing or emerging technologies
- Assistance in addressing technological performance and market analysis
- Addressing general technology problems

Resources

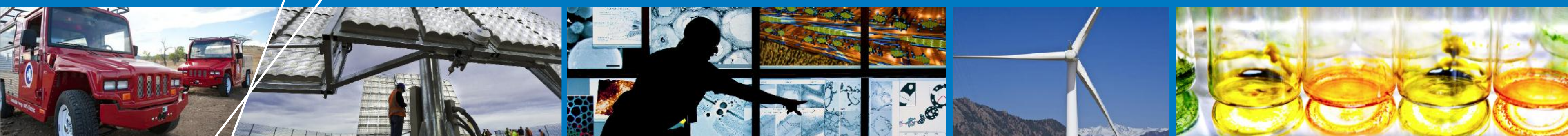
- **Technology listing**
  - http://www.nrel.gov/technologytransfer/technologies_listed.html
  - Spend some time on our website to identify capabilities of interest
  - Facilities, personnel, equipment
  - http://www.nrel.gov/
- **Energy Innovation Portal**
  - 17,000+ patents from all labs
  - 850+ business-friendly marketing summaries
  - http://techportal.eere.energy.gov

Next Steps

- **Schedule your one-on-one to speak with Yoriko**
  - Complete post-webinar form – ***or*** –
  - Visit https://nrel.acuityscheduling.com
- **Download guidance/forms**
  - http://techtransfer.energy.gov/LicensingGuideFINAL.pdf
  - http://www.nrel.gov/technologytransfer/licensing_agreements.html

Amber LEDs for Solid-State Lighting:

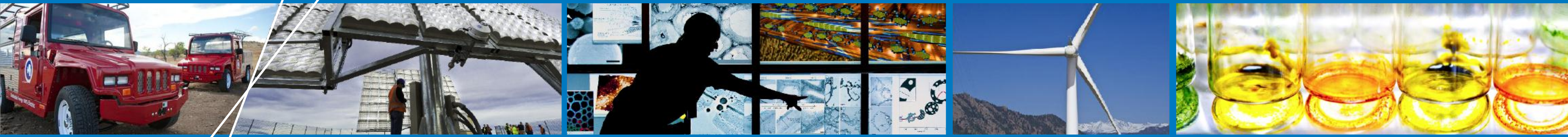
White light with unprecedented efficiencies



Q&A

Amber LEDs for Solid-State Lighting:

White light with unprecedented efficiencies



Thank you!